

Motivation of Climate Change Investment and Risk Exposure

New Perspective from Game Model

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Abstract

The common and individual uncertainties are the main factors influencing the motivation of climate change investment for each country. By distinguishing and involving the three effects of climate change investment on utility, strategic game model with rationality hypothesis is proposed and simulated to evaluate the relationship between the investment motivation and individual risk exposure due to individual uncertainties. The positive correlation between the risk exposure and investment motivations is confirmed. The negative influences of risk exposure on utilities of game equilibriums whatever the dynamic strategies are also tested. Upgrade of the structure of economy and enhancement of the anti-fluctuation capacity for the economy shock of global warming deserve to be the focus and priority.

Keywords

Investment; Risk Exposure; Climate Change; Game Model

Introduction

Over the past several decades, global warming and climate negotiation have become more and more severe in spite of the progress on the scientific and sociological researches. There's still a huge gap between the attitudes towards the responsibility and schedule of implementation. Apart from political and economic concerns, the uncertainties of global warming together with its impact are the major obstacles on the way to reaching a widely acceptable and binding consensus for all countries. EU insists that actions should be taken immediately due to irreversible risk of temperature increment on human being's living environment, while the United States believes that it's economical and feasible to make use of future technology progress to cope with the issue. Different perspectives on the reaction to uncertainties are the essential factors destabilizing the direction of climate negotiation.

Generally, the uncertainties as mentioned above can be classified into two categories: common uncertainties and individual uncertainties. The global greenhouse gas (GHG) concentration and the temperature increment together with its trajectory under BAU (business-as-usual) scenario in the future belong to the former type as it's confronted in each country fairly. Although the temperature increment due to the GHG concentration is triggered by the combined effects of individual mitigation fundamentally, the externality of GHG results in the lack of motivation to conduct carbon abatement for each country alone. Chander and Tulkens (2006), Wood (2011) and other researchers (Desombre, 2004; Hovi, Sprinz and Bang, 2012; Kroll and Shogren, 2008) have already revealed the failure of cooperation from perspective of theoretical game theory.

The other type of uncertainty is based on individual properties including initial GDP growth, the tolerance of temperature increment on individual GDP et al. The diversities of industry structures and choices of competitive industries may affect the stabilities and risk resistance capacities for each country under different temperature increment scenarios. Compared with developed countries, the developing countries, especially the African and Southeast Asian nations may suffer more severe loss with higher uncertainty for their inadequate precaution and high dependence on the tender agriculture industry (Hope, 2006; Maddison, 2003; Nordhaus and Boyer, 2000; Tol, 2002). Such risk exposures connected with individual properties may attract more attention for their own interests and trigger their subjective initiatives. Then the way how the risk exposure will influence the negotiation strategies is introduced. Such relationship is investigated in this article with theoretical model and

simulations. Based on rationality hypothesis, the three effects of climate change investment on utility are distinguished and involved in our dynamic game model. Simulation together with comparison is carried out. More information about the model is introduced in Section 2. Simulations together with evaluation are presented in Section 3, followed by discussions and conclusions in Section 4.

Theoretical Model

Utility and Uncertainties

We posit a constant relative risk aversion (CRRA) social utility function for each rational country:

$$Utility_i = \int e^{-\delta t} \times U_{i,t} dt = \int e^{-\delta t} \times \frac{C_{i,t}^{1-\eta_i}}{1-\eta_i} dt. \quad (1)$$

where $Utility_i$, $U_{i,t}$, η_i and δ refer to the net present utility, utility at time t , index of risk aversion and discounting rate for country i respectively. $C_{i,t}$ means the disposable consumption at time t which can be connected with GDP growth rate g_t :

$$C_t = \exp\left(\int_0^t g_s ds\right). \quad (2)$$

In the absence of global warming, real GDP and consumption can keep a constant growth g_0 , but the temperature increment would have a simplified linear effect on real GDP growth as Dell, Jones and Olken(2009) estimated:

$$g_t = g_0 - \gamma T_t. \quad (3)$$

The marginal effect of temperature increment at time t (T_t) on GDP growth is γ . As just discussed, the temperature increment and the marginal effect parameter γ belong to the two categories of uncertainties respectively. Although lots of researches have calibrated these parameters, the results are not always consistent or precise due to various restrictions of each model. One of the widely accepted solutions is to involve probability theory and to estimate the expected utility.

For the common uncertainty, i.e. T_t , the temperature increment at horizon year ($H=100$) has been fitted by Pindyck(2012), Newbold and Daigneault(2009) with assumptions that the mean, 5% and 1% points temperature increments are 3°C, 7°C and 10°C respectively. Three-parameter (i.e. r_T, λ_T, θ_T) Gamma function fits the uncertainty distribution well

with the following PDF (probability density function):

$$f_T(x; r_T, \lambda_T, \theta_T) = \frac{\lambda_T^{r_T}}{\Gamma(r_T)} (x - \theta_T)^{r_T-1} e^{-\lambda_T(x-\theta_T)}, x \geq \theta_T. \quad (4)$$

For the individual uncertainty, i.e. γ , the marginal effect of temperature increment on GDP growth can be calibrated based on the individual exponential loss function information obtained from IAMs researches as there is a linear relationship between β and γ theoretically¹. Given the trajectory of temperature increment T_t proposed by Weitzman(2009) and applied by Pindyck(2012), Figure 1 shows the change of loss function value due to the temperature increment at horizon year, parameter β and time t .

$$Loss(T) = e^{-\beta(T)^2}. \quad (5)$$

$$T_t = 2T_H \times [1 - (\frac{1}{2})^{t/H}]. \quad (6)$$

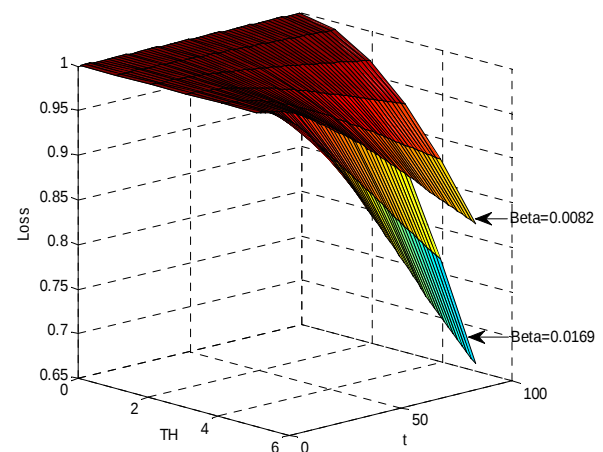


FIG. 1 THE RELATIONSHIPS OF $Loss(T_t)$, T_t AND β

Effects of Climate Change Investment and Motivations

The three effects of climate change investment on utility are distinguished: the positive, negative and spillover effects. If inv_i represents the percentage of climate change investment to GDP for country i , then the amount of disposable consumption will be reduced which is defined as the negative effect of inv_i on utility. On the other hand, climate change investment will boost the original GDP growth with marginal parameter ξ as it's implemented as extra investment.

¹ With Eq. (1) to (6), the theoretical relation between γ and β can be solved out:

$$\gamma = \frac{T_H}{H \times [2 + \frac{1}{\ln(0.5)}]} \times \beta$$

Therefore the modified GDP growth and disposable consumption due to the positive and negative effects are adjusted as:

$$g_{i,t}^* = g_{i,0} \times (1 + \xi_i \times inv_i) - \gamma_i T_i. \quad (7)$$

$$C_{i,t}^* = C_{i,t} \times (1 - inv_i) = (1 - inv_i) \times \exp\left(\int_0^t g_{i,s}^* ds\right). \quad (8)$$

On the other hand, the externality of global warming determines the spillover effect of climate change investment. Supposing that the relationship between the upper boundary of temperature increment T_{Up} and global climate change investment can be quantified as function Φ , then each country's investment decision inv_i will partially influence the T_{Up} with its GDP related weighting factor w indirectly. Compared to the temperature increment uncertainty under no investment scenario, T_{Up} should promote each country's present net utility as the original distribution of common uncertainty will be updated with Bayesian theorem. In other words, the original PDF for the temperature increment in the future $f_T(x; r, \lambda, \theta)$ is Bayesian updated to $\tilde{f}_T(x; r, \lambda, \theta)$ as Eq. (10) shows:

$$T_{Up} = \Phi(inv_{world}) = \Phi\left(\sum_i w_i \times inv_i\right). \quad (9)$$

$$\tilde{f}_T(x; r, \lambda, \theta) = \frac{f_T(x; r, \lambda, \theta)}{\int_{\theta_T}^{T_{Up}} f_T(x; r, \lambda, \theta) dx}, \theta \leq x \leq T_{Up}. \quad (10)$$

$$Utility_i = \Psi_i(inv_i, f_{\gamma_i}; inv_j) = \int_0^{+\infty} \int_{\theta_T}^{+\infty} e^{-\delta t} \times \frac{(C_{i,t}^*)^{1-\eta_i}}{1-\eta_i} \times \tilde{f}_T \times f_{\gamma_i} dT d\gamma dt. \quad (11)$$

If the three effects of climate change investment are combined, every rational negotiator has incentives to choose the optimal investment to maximize its own utility. Apart from common uncertainties, individual uncertainties will also affect their motivations. By means of integration of the Eq. (1) to (10), the present net utility of country i can be further expressed as $\Psi_i(inv_i, f_{\gamma_i}; inv_j)$. Given the other countries' investment information inv_j and individual uncertainty f_{γ_i} , the optimal amount of climate change investment for county i should meet the target of maximum Ψ_i . Hence, $OptInv_i = \Theta_i(f_{\gamma_i}; inv_j)$ is employed to represent the optimal reaction which is determined by inv_j and individual uncertainty f_{γ_i} . By comparing the gap of $OptInv_i$ under different assumption of f_{γ_i} ,

the relationship of climate change investment motivation and risk exposure then can be evaluated.

Furthermore, the non-cooperative game equilibriums can also be worked out by involving the dynamic decision steps for each country under complete information hypothesis. The influence of individual uncertainty f_{γ_i} on the game equilibriums can be examined as well. With the backward induction method (Aumann, 1995), the theoretical game equilibriums of dynamic game model for two countries involve three scenarios as table 1 shows. 'First', 'second' and 'simul' mean the three strategies, and $OptInv_i^{first/second/simul}$, $Utility_i^{first/second/simul}$ represent climate change investment and utility of equilibriums respectively.

Simulation and Comparisons

For the individual uncertainty, three groups with different hypotheses are simulated and compared. The probability density function f_{γ_i} is fitted by taking the mean loss for $T_H=2.5^\circ\text{C}$ to be 3% GDP, and the 17% point and 83% point to be 1% and 4.8% of GDP respectively for Group 1. The risk exposures are adjusted by means of increasing and decreasing the variance with the same expectation for Group 2 and Group 3 respectively.² Figure 2 shows the distribution of parameter γ . Generally, the risk exposure meets the order: Group 2>Group 1>Group3.

In comparison with the optimal reactions of three groups as Figure 3 shows³, the optimal reaction to high risk exposure country tends to be more than that with low risk exposure. When $inv_j=3\%$, the optimal reaction of Group 1 is 1.248% GDP, higher than 1.246% of Group 3 and lower than 1.251% of Group 2 respectively. The simulation results are rational and in accordance with the reality because the optimal reaction refers to an optimal balance of the three effects of climate

² For three-parameter Gamma distribution, the mean, variance and skewness

are $E(x) = r / \lambda + \theta$, $Var(x) = r / \lambda^2$ and

$Skew(x) = 2r / \lambda^3$ respectively.

³ The other common parameters include initial GDP growth $g_0=4.5\%$, risk aversion $\eta = 2$, marginal promoting effect of climate change investment on GDP growth $\xi = 1$, time preference $\delta = 0$ and initial temperature uncertainty $(r_T, \lambda_T, \theta_T) = (3.8, 0.92, -1.13)$ which is in accordance with Pindyck(2012).

TABLE 1 THEORETICAL EQUILIBRIUMS FOR DYNAMIC GAME MODEL WITH TWO COUNTRIES

Scenarios	Country i moves firstly	Country j moves firstly	Simultaneously
Country i	$OptInv_i^{first}, Utility_i^{first}$	$OptInv_i^{second}, Utility_i^{second}$	$OptInv_i^{simul}, Utility_i^{simul}$
Country j	$OptInv_j^{second}, Utility_j^{second}$	$OptInv_j^{first}, Utility_j^{first}$	$OptInv_j^{simul}, Utility_j^{simul}$

Notes: This table only simulates two-country scenario which can be adjusted to the multi-country situation.

TABLE 2 HYPOTHESES AND CALIBRATION RESULTS FOR INDIVIDUAL UNCERTAINTY

	Hypotheses of (1-Loss(2.5°C))			Three parameters for γ		
	Mean	17% Point	83% Point	r	λ	θ
Group1	3%	1%	4.8%	11.141	22329	-2.85E-04
Group2	3%	0.5%	5.3%	6.935	13815	-2.87E-04
Group3	3%	1.5%	4.3%	20.72	41624	-2.85E-04

Notes: the parameter values for γ are in accordance with the hypotheses respectively.

TABLE 3 NON-COOPERATIVE DYNAMIC GAME MODEL EQUILIBRIUMS OF THREE STRATEGY SCENARIOS

	i moves firstly			j moves firstly			Simultaneously		
	Group 1	Group 2	G3	G1	G2	G3	G1	G2	G3
$OptInv_i$	1.342%	1.343%	1.341%	1.337%	1.336%	1.334%	1.341%	1.339%	1.337%
$OptInv_j$	0.455%	0.455%	0.455%	0.560%	0.560%	0.560%	0.455%	0.454%	0.454%
$Utility_i$	-21.7745	-21.7756	-21.7738	-21.7745	-21.7756	-21.7738	-21.7745	-21.7756	-21.7738
$Utility_j$	-66.4760	-66.4760	-66.4760	-66.4760	-66.4760	-66.4760	-66.4760	-66.4760	-66.4760

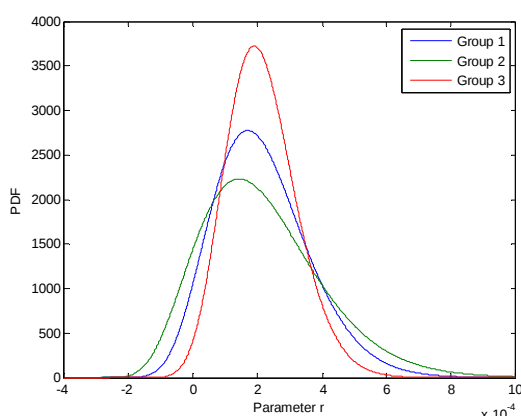
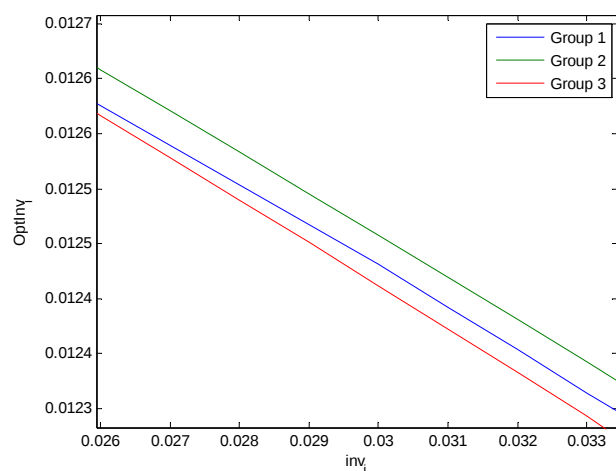


FIG. 2 PROBABILITY DENSITY DISTRIBUTION OF PARAMETER FOR GROUP 1 TO 3

FIG. 3 $OptInv_i = \Theta_i(f_{\gamma_i}; inv_j)$ FOR GROUP 1 TO 3

change investment. With higher risk exposure, the room of improvement in spillover effect would be

more attractive and significant, which will trigger the higher investment of climate change. In other words, high risk exposure will promote the motivation of climate change investment.

In addition, dynamic game equilibriums in Table 3 also show the differences due to the risk exposures⁴. Although the equilibriums of investment are not consistent in each dynamic strategy scenario, the utility differences are significant. Whatever the dynamic strategy scenario is, the utility of country i meets the order constantly: Group 3>Group 1> Group2. The simulation results are also inspiring. It indicates that the risk exposure itself has much more determining power than the game strategies under non-cooperative scenarios in influencing the utilities of each country, which means that we should give the priority to the enhancement of the anti-fluctuation capacity for the economy shock of global warming.

Discussions and Conclusion

The effects of risk exposures on optimal reactions together with game equilibriums are evaluated. By distinguishing the three effects of climate change investment on utility, the motivation of climate change investment are investigated with rationality hypothesis. Simulations results reveal that the higher risk exposure

⁴ The other country/sector j meet the following initial hypotheses which is based on reality:

$g_{0j}=1.5\%, \xi=1, \delta=0$ and

$(r_{\gamma}, \lambda_{\gamma}, \theta_{\gamma}) = (103.8, 411600, -1.745e-4)$.

is, the more investment one nation is incentive to make, which means that the fragility of economy may have a significant effect on the motivations. For countries with high-dependence on agriculture and other industries susceptible to global warming, it's rational and motivated to invest more. Therefore, it's advisable for developing countries, especially African and Southeast Asian nations to upgrade the industry structure and to take precautions to cope with the fluctuation of climate change, which will not only be conducive to the stability of future utility, but also enhance their bargaining power in climate negotiation. Moreover, the results of game equilibriums under different dynamic strategies also suggest the benefits of reduction of the risk exposure. Countries with higher risk exposure may have to face more severe decrease of utility. Such decrement is significant whatever the adopted dynamic strategies are, leading to the cognition that more attention should be paid to the improvement of economy structure and anti-fluctuation capacity compared to the negotiation strategies themselves.

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